IN THE SPECIFICATION

Add the following sentence as the first paragraph following the title.

The present application is based on prior U.S. application No. 09/580,560, filed on May 30, 2000, which is hereby incorporated by reference, and priority thereto for common subject matter is hereby claimed.

Amend the title as follows.

LOW VOLTAGE ~~OUTPUT DRIVE~~AMPLIFYING CIRCUIT

Amend the text from page 1, line 6, through page 3, line 30 as follows.

~~The present invention relates in general to electronic circuits and, more particularly, to depletion mode metal oxide semiconductor (MOS) devices in a series configuration.~~

~~Supervisor circuits find use in most if not all system supervisor applications. Systems requiring supervisor circuits are diverse and cover a wide range of uses from battery-powered equipment, computers, embedded systems, and microprocessor power supply monitoring. The supervisor circuit monitors a supply voltage and provides a reset signal to the microprocessor in the presence of a low supply voltage. If the supply voltage falls below some specified operating threshold the supervisor circuit triggers a reset of the microprocessor. Typically, the supervisor circuit consist of a comparator to monitor changes in the supply voltage, and a trigger circuit to reset the microprocessor upon a supply voltage drop. If the comparator detects a change in supply voltage with respect to a voltage reference, the comparator sends a signal to the~~

~~trigger circuit to reset the microprocessor.~~ ~~As an example, a supervisor circuit monitors the supply voltage line of a microprocessor and compares the supply voltage to a voltage reference. If the supply voltage to the microprocessor drops below the voltage reference the supervisor circuit detects the voltage drop and resets the microprocessor, and puts the microprocessor in a fault mode. The microprocessor stays in the fault mode until the supply voltage increases above the voltage reference, at which time the supervisor circuit removes the reset and the microprocessor thereafter operates in a normal mode.~~

~~The output of current prior art supervisor circuits have a state at which it can not guarantee an output if the supply voltage drops below some threshold voltage. The point below the threshold voltage at which the output of the supervisor circuit is not guaranteed is dependent upon the minimum voltage required to operate the trigger circuit. Typical implementations of a trigger circuit in the prior art are open drain or complimentary transistor configurations. Both of these configurations require a minimum voltage to be applied to the devices before the devices are operative. As a result, if the supply voltage to the microprocessor drops below the minimum voltage required to operate the trigger circuit, the output of the supervisor circuit can not be guaranteed and the microprocessor may inadvertently fall out of a fault mode. Also, for low voltage applications the supply voltage may operate close to the minimum voltage required to operate the trigger circuit, again resulting in an operation where the microprocessor may fall out of a fault mode.~~

~~Low voltage applications typically require linear regulators. A linear regulator takes in an unregulated input voltage and converts it to a regulated output voltage. The prior art typically uses an enhancement mode p-type transistor and a controller to provide the regulation. When the enhancement mode p-type transistor is turned off by the~~

~~controller, there is some leakage current through the enhancement mode p-type transistor. The leakage current is typically inversely related to the threshold voltage of the enhancement mode p-type transistor. Thus, you have to make the threshold voltage of the enhancement mode p-type transistor higher to reduce the leakage current. However, the input voltage must be at least the threshold voltage of the enhancement mode p type transistor to turn the linear regulator on. Therefore, to operate a linear regulator at a low voltage results in a high leakage current through the device.~~

~~With advancing technology, most supply voltages to systems will drop down to the minimum voltage required to operate current prior art enhancement mode devices. For example, if the supply voltage of a microprocessor operates close to the minimum voltage required to operate the trigger circuit the microprocessor may experience inadvertent fault or operating modes. Furthermore, it would not be possible for a system to have a linear regulator operate at a low voltage with little or no leakage current using prior art enhancement mode devices. Thus, to meet advancing technology, a need exists for a circuit which can operate close to zero volts to replace trigger circuits presently used in prior art supervisor circuits to guarantee an output of the supervisor circuit for all input voltage levels. Also, the circuit must provide a linear regulator to operate in a low voltage environment without a high leakage current as seen with current prior art technology.~~

The present invention relates in general to electronic circuits and, more particularly, to amplifying circuits that operate at low supply voltage levels.

As integrated circuits achieve higher levels of integration, there is a corresponding need to operate the circuits at reduced voltage levels in order to maintain power

dissipation at manageable levels. For example, it is anticipated that future microprocessors and other digital circuits will need to operate with power supply voltages of 0.5 volts to maintain an acceptable die temperature. Future circuits are expected to operate with even lower supply voltages.

A low supply voltage typically is produced by a voltage regulator implemented as an integrated circuit. The regulator includes an error amplifier to sense the supply voltage and feed back an error signal that adjusts the voltage level to maintain regulation. The error amplifier and its associated circuitry preferably also operate at a low voltage in order to achieve a low power dissipation by the regulator circuit.

Most if not all integrated circuit amplifiers operate only at supply voltages that exceed the conduction threshold of the integrated circuit's transistors. When the supply voltage drops below the conduction threshold level, the transistors cease to function and gain of the amplifiers drops quickly to zero. In a case where the amplifier is being used in a voltage regulator, the rapid loss of gain can cause the regulator's output voltage to transition out of its specified range, which can damage both the regulator and the circuits operating from the regulator's output supply voltage.

Accordingly, there is a need for an amplifier circuit and method of amplifying that maintains functionality at lower supply voltages than what is currently available.

The paragraph beginning on page 4, line 4 is amended as follows.

FIG. 1 is a block diagram of a supervisor circuit and microprocessor;

FIG. 2 is a waveform plot of an output signal of a prior art supervisor circuit;

FIG. 3 is a waveform plot of an output signal of a supervisor circuit;

FIG. 4 is a schematic diagram of a trigger circuit of the supervisor circuit;

FIG. 5 is a block diagram of a prior art linear regulator circuit;

FIG. 6 is a block diagram of a first regulator circuit;

FIG. 7 is a schematic diagram of a second regulator circuit including an amplifier;

FIG. 8 is a schematic diagram of the amplifier; and

FIG. 9 is a schematic diagram of an alternate embodiment of the amplifier.

Please insert the following text after page 12, line 17.

In the following figures, elements having the same reference numbers have similar functionality.

FIG. 7 is a schematic diagram of a voltage regulator 100, including an amplifier 102, transistors 104 and 106, resistors 108 and 110 and capacitors 112 and 114. Voltage regulator 100 receives an input supply voltage V_{SUPP} on a supply terminal coupled to a node 118 and produces a regulated voltage V_{REG} at an output 120. Regulator 100 is suitable for integrating on a semiconductor die to form an integrated voltage regulator circuit.

Resistors 108 and 110 are scaled to a predetermined ratio and serially coupled between output 120 and ground potential to function as a voltage divider that monitors or senses regulated voltage V_{REG} and provides a divided sense voltage V_{SENSE} on a node 122.

Amplifier 102 comprises a differential input-differential output voltage or transconductance amplifier configured to operate from supply voltage V_{SUPP} at values approaching zero volts. In one embodiment, V_{SUPP}=0.3 volts. An inverting input is coupled to node 122 to receive sense voltage V_{SENSE} and a non-inverting input at a node 124 receives a reference voltage V_{REF1}. An error voltage $V_{ERR}=(V_{REF1}-V_{SENSE})$ applied across the inverting and non-inverting inputs is amplified to produce a differential output signal $V_{AMP}=(V_{AMP+}-V_{AMP-})$ across output nodes 128 and 126, where V_{AMP-} and V_{AMP+} are the component signals of V_{AMP} and have opposing phases.

The transient characteristics of amplifier 102 are a function of the impedances of nodes 126 and 128, which are determined by loop stabilization capacitors 112 and 114 and the gate capacitances of transistors 104 and 106, and therefore are highly capacitive. Accordingly, the output stage of amplifier 102 is configured to drive nodes 126 and

128 with currents high enough to meet specified transient response characteristics and low enough to ensure loop stability under the specified operating and environmental conditions of regulator 100.

Transistors 104 and 106 are formed as metal oxide semiconductor field effect transistors (MOSFET) operating in the depletion mode. Transistor 104 is an n-channel MOSFET while transistor 106 is a p-channel MOSFET as shown in FIG. 7. Transistors 104 and 106 are serially coupled between input 120 and output 118, with their sources being commonly coupled to a node 127 to function as a pass element of regulator 100. Because transistors 104 and 106 are formed as series coupled depletion mode devices, their conduction thresholds are negative, so they are conductive even with zero volts of gate to source bias potential. As a result, regulator 100 is able to maintain regulation when the input-output voltage differential ($V_{SUPP}-V_{REG}$) approaches zero volts. In one embodiment, input-output voltage differential ($V_{SUPP}-V_{REG}$) is 0.2 volts. In one embodiment, transistors 104 and 106 are formed to have typical conduction thresholds of -0.2 volts, thereby providing conduction at zero volts of gate to source potential.

In operation, assume that V_{SUPP}=0.3 volts, V_{REF1}=0.125 volts and V_{REG} initially is zero, with a target value of 0.25 volts. Further assume that the resistances of resistors 108 and 110 are equal, so $V_{SENSE}=V_{REG}/2$. Since V_{REG} is zero, V_{SENSE} is zero as well, and therefore less than V_{REF1}, so V_{AMP-} decreases while V_{AMP+} increases, turning on transistors 104 and 106 to couple a current I_{LOAD} from input 118 to output 120 to charge an external load capacitor 130 to increase the value of V_{REG}. I_{LOAD} continues to flow until V_{REG} reaches its target value of 0.25 volts, at which time $V_{SENSE}=V_{REF1}$=0.125 volts, approximately. While V_{REG} is at its target value, amplifier 102 controls the conduction of transistors 104 and 106 such that I_{LOAD} flows at a level sufficient to supply the current requirements of the

load circuitry (not shown) operating from V_{REG}, thereby maintaining regulation. In one embodiment, regulator 100 is configured to supply I_{LOAD} to a magnitude of one hundred milliamperes.

Under normal conditions V_{REG} does not exceed its target value, but load switching or system noise may result in momentarily increasing V_{REG} to a value greater than the 0.25 volt target value. If that occurs, amplifier 102 produces values of V_{AMP+} and V_{AMP-} that reduce the conduction of transistors 104 and 106 to allow the flow of current to the load circuitry to be supplied from charge stored on capacitor 130 until V_{REG} decays to its target value.

FIG. 8 shows a schematic diagram of amplifier 102 in further detail, including depletion mode MOSFETs 140-144.

Transistor 140 is an n-channel device whose gate and source operate at ground potential to function as a current source that supplies a bias current I_{BIAS} to a common node 145. Transistors 143-144 are p-channel devices whose sources and gates are coupled to node 118 to function as current sources or high impedance loads that provide amplifier 102 with a high open loop gain. Alternatively, high impedance resistors or other types of devices can be used to perform functions equivalent to those performed by transistors 140 and 143-144. However, such alternative devices have the disadvantage of consuming a larger area of a semiconductor die, and therefore have a higher cost, than transistors 140 and 143-144.

Transistors 141-142 are configured as a differential pair receiving V_{SENSE} and V_{REF1} as a differential input signal that routes I_{BIAS} through transistors 143 and 144 to produce component differential signals V_{AMP+} and V_{AMP-} of differential output signal V_{AMP}. Nodes 126 and 128 are relatively high impedance nodes which allow amplifier 102 to be easily compensated by capacitors 112 and 114 (shown in FIG. 7) when operated in a closed loop condition such as that of regulator 100.

The use of depletion mode devices for transistors 140-144 maintains their conduction and allows amplifier 102 to function at values of supply voltage V_{SUPP} that approach zero. Accordingly, amplifier 102 is well suited for low voltage applications such as in regulating the supply voltage of a low voltage microprocessor. Although amplifier 102 is shown and described as being used as an active component of voltage regulator 100, it is evident that amplifier 102 is suitable for use in virtually any other analog application that would benefit from its economical structure and low voltage operation.

FIG. 9 shows a schematic diagram of an amplifier 170 receiving oppositely phased differential input signals V_{IN+} and V_{IN-} and producing a single ended amplified output signal V_{AMP2} at an output 169. Amplifier 170 is coupled to a supply terminal 118 to operate from a supply voltage V_{SUPP}. Amplifier 170 includes depletion mode MOSFET transistors 140-144 and 161-164 and a level shift circuit 133, and is suitable for use as a low voltage amplifier in an analog amplification application such as an error amplifier in a voltage regulator. In an alternate embodiment, amplifier 170 is configured with a high transconductance or voltage gain for use as a comparator.

Transistors 140-144 function as a first or input stage of amplifier 170 and operate in a fashion similar to that described in the description of FIG. 8. Consequently, the first stage has the benefit of operating at values of V_{SUPP} that approach zero.

Level shifter 133 level shifts component differential signals V_{AMP+} and V_{AMP-} to produce level shifted signals V_{LS+} and V_{LS-} on node 131 and 129, respectively. V_{LS+} and V_{LS-} retain the information contained in V_{AMP+} and V_{AMP-} but are level shifted by a DC voltage in order to bias transistors 161-164 for the desired operation. For example, if class A operation is desired, the level shifting DC voltage may be set to one-half

the value of supply voltage V_{SUPP}. Other level shifting voltages may be used to provide other classes of operation.

Transistors 161-164 function as a second or output stage of amplifier 170 whose operation is described as follows. Transistor 161 is an n-channel device controlled by component signal V_{LS-} to set the conduction between supply terminal 118 and a node 166. Transistor 162 is a p-channel device controlled by component signal V_{LS+} to set the conduction between node 166 and output 169. The conduction of transistors 161-162 determine the level of a current I_{STACK1} that is routed from supply terminal 118 to output 169 as a first component of output signal V_{AMP2}.

Transistor 164 is a p-channel device controlled by component signal V_{LS-} to set the conduction between ground potential and a node 168. Transistor 163 is an n-channel device controlled by component signal V_{AMP+} to set the conduction between node 168 and output 169. The conduction of transistors 163-164 determines the level of a current I_{STACK2} that is routed from ground to output 169 as a second component of output signal V_{AMP2}.

Output voltage V_{AMP2} is developed from an output current I_{OUT} that flows from output 169 to a load 180 as the difference between currents I_{STACK1} and I_{STACK2}.

It can be seen that the present invention provides an amplifier that occupies a small die area and has a low cost while operating with an input-output voltage differential approaching zero volts. First and second depletion mode transistors operate in response to first and second signals, respectively, to route a first current from a first supply terminal to an output of the amplifier. Third and fourth depletion mode transistors operate in response to the first and second signals to route a second current from a second supply terminal to the output. The first and second currents are summed to develop an output signal at the output. The negative thresholds inherent in depletion mode transistors

ensures active functionality with zero volts gate to source potential, which allows the amplifier to function at very low supply voltages, even approaching zero volts. The first or second signal can be coupled to a reference voltage to operate the amplifier as a voltage regulator.